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**TRANSIENT INVOLUNTARY MIRROR WRITING TRIGGERED BY
ANXIETY**

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Abstract

Mirror writing (MW) has mainly been observed in left hemisphere damaged patients writing with the left hand. This study evaluated the presence of MW in 24 patients with Mild Cognitive Impairment (MCI). We found that MW is not a typical feature of MCI. However, one woman(FC), mis-labelled initially with MCI but in fact affected by anxiety, showed florid MW when writing with her left hand, which resolved as her anxiety receded. This case study supports anecdotal reports of MW triggered by anxiety, and the features of FC's performance indicate a motor rather than a perceptual basis for the phenomenon.

Key words: Mirror writing, MCI, anxiety, perceptual, motor

Introduction

Mirror writing (MW) refers to the production of individual letters, words or word strings in reversed direction (Della Sala & Cubelli, 2009). When held to a mirror, these letters or words can be read normally (Critchley, 1928; McIntosh & Della Sala, 2012). Many children write backwards *spontaneously* during literacy development (Cornell, 1985; Cubelli & Della Sala, 2009; Gordon, 1920; Della Sala & Cubelli, 2007; Fischer, 2011; Fischer & Tazouti, 2011). MW has been practised *deliberately* by some individuals (Allen, 1896; McIntosh, De Lucia & Della Sala, 2014; Schott, 1999), but it can also arise *involuntarily* in adults following brain damage (e.g., Balfour, Borthwick, Cubelli, & Della Sala, 2007).

Involuntary MW has been observed mainly in left hemisphere damaged patients writing with their left hand, and is usually discovered when right hemiplegia forces the left hand to pick up a pen (see review in Della Sala & Cubelli, 2007). However, there are hints, including anecdotal reports from early literature, that MW may also appear in patients with cognitive impairment. Allusions to MW in people with insanity or with *dementia precox* can be found in an encyclopaedia entry by Savage (1892), in Bianchi's treaty on psychiatry (1906), in Laprade's essay on MW (1905, p. 58) as well as in Critchley's seminal monograph (1928). The recent literature contains one brief case report of MW in Alzheimer's Disease (de Silva and Gunatilake, 2005), and a very short Research Letter reporting MW errors in 17 of 33 Chinese patients with Alzheimer's Disease, though without reporting the conditions of testing or the nature of the MW errors (Wang, Peng, Cai & Li, 2007). However, most MW errors are for single letters or digits, and reversal of complete words or phrases is extremely rare. In recognition of this, Balfour et al. (2007) introduced the distinction between partial MW (of individual letters) and complete MW

(of whole words and phrases). Partial MW can occasionally be observed in healthy people (Schott, 2007), particularly the elderly (Balfour et al, 2007; Kuzuya, Yamamoto and Kuzuya, 1991), when asked to write with their non-preferred hand; but complete MW is clearly pathological.

Two main classes of explanation for MW have been proposed: perceptual and motor. The *perceptual hypothesis* stipulates that MW stems from mis-representation of how the letters should look; accordingly mirror-writers should visualise letters and words backward (Orton, 1928; Heilman, Howell, Valenstein, & Rothi, 1980). The perceptual hypothesis thus predicts that MW should be associated with a facility for perceptual recognition of mirrored letters and words. Case reports of mirror-reading coupled with mirror writing have appeared in the neuropsychological literature (Gottfried, Sancar, & Chatterjee, 2003; Lambon-Ralph, Jarvis, & Ellis, 1997; Pflugshaupt et al., 2007) but, in these patients, the mirror-writing may be a deliberate adaptation to reversed perceptions, and not strictly involuntary.

The *motor hypothesis* posits that MW concerns action representations for writing. The classical version of this hypothesis (Critchley, 1928) proposes that the critical motor representation specifies sequences of muscle commands for writing with the dominant hand. If a person tries to execute such a sequence with the non-dominant hand, the action will be mirror-reversed, due to anatomical mirroring between the arms, unless a cognitive effort is made to first transform the motor commands. This idea predicts that involuntary mirror-writing should be restricted to the non-dominant hand, and should be more readily observed amongst people with significant cognitive depletion (Critchley, 1928; Della Sala & Cubelli, 2007; McIntosh & Della Sala, 2012). Unlike the perceptual hypothesis,

the motor account suggests that people with this symptom should continue to visualise words and letters normally, having no special facility for mirror-reading.

The present study was set-up to test the prediction of classical motor hypothesis, that cognitive depletion in association with non-dominant hand use should lead to abnormally high rates of involuntary MW errors. The target population for this study was patients with Mild Cognitive Impairment (MCI), a precursor of Alzheimer's Disease (Petersen, 2004). Nothing is previously known about MW rates in this population and, in fact, our investigation in a group of 24 patients with MCI, reported here, found no increased prevalence of MW above an age-matched control sample, providing no support for the classical motor hypothesis. However, during the course of this study, we encountered by serendipity the case of a right handed patient (FC) who did not satisfy the diagnostic criteria for MCI, yet who showed transient complete involuntary left hand MW during a particularly stressful period of her life. The possibility that high levels of stress could cause MW has been hinted at in the early literature (Critchely, 1928; Fuller, 1916). However, this is the first case of MW due to anxiety to be described in detail, or followed longitudinally to remission. Moreover, the pattern of impaired and spared cognitive abilities shown by FC allowed us to disentangle two competing accounts of MW in this single case. In particular, her MW was confined to the left hand, and was not coupled with better mirror reading skills than those of the controls, consistent with a motor rather than a perceptual explanation.

Group study of MCI cohort

This study included 24 right-handed people with MCI (15 females, 9 males; median age 75 years, range 58-82; median years education 8, range 2-18) and 19 healthy controls (11

females, 8 males; median age 64 years, range 60-80; median years education 13, range 5-18). All the MCI patients were diagnosed according to formal criteria (Petersen, 2004; Winblad et al., 2004) requiring: 1) change in cognition recognized by the affected individual or by observers; 2) objective impairment in one or more cognitive domains; 3) no presence of dementia. Moreover, they all had a normal neurological examination, and performed normally in activities of daily living. The two groups did not differ significantly for years of education (Mann-Whitney U (43) = 177.0, $p = 0.13$), though the MCI group was slightly older (Mann-Whitney U (43) = 146.0, $p < 0.05$). The performance of the two groups across a range of neuropsychological tests is reported and compared in Table 1.

Table 1.

MCI patients' and healthy controls' performance on the neuropsychological battery. Within each data cell, the upper value shows median (interquartile range), with the minimum-maximum range indicated below. Non-parametric comparisons between groups are shown.

Test (score range)	MCI (N=24)	Healthy controls (N=19)	Mann-Whitney U Test
EHI Laterality Quotient (-100-100) (Oldfield, 1971)	100 (0) 80-100	100 (0) 60-100	U (43) = 255.0 $p = 0.19$
Mini Mental State Examination (0-30) (Folstein et al., 1975)	26 (7) 23-30	29 (2) 24-30	U (43) = 146.5 $p < 0.05$
Frontal Assessment Battery (0-18) (Dubois et al., 2000)	13 (5) 8-18	17 (2) 10-18	U (43) = 96.0 $p < 0.005$
Prose Memory - Immediate recall (0-8) (Spinnler and Tognoni, 1987)	3.6 (2.8) 0-6.8	5.8 (2) 3.3-7.7	U (43) = 89.0 $p < 0.005$
Prose Memory - Delayed recall (0-8) (Spinnler and Tognoni, 1987)	2.1 (5.2) 0-6.7	5.7 (1.6) 3.2-7.7	U (42) = 64.5 $p < 0.0005$
Digit Span forward (2-9) (Orsini et al., 1987)	4 (1) 3-6	6 (1) 4-8	U (43) = 100.5 $p < 0.005$
Digit span backward (2-9) (Orsini et al., 1987)	3 (2) 2-5	4 (2) 3-7	U (43) = 111.5 $p < 0.005$

Visual search (0-60) (Spinnler and Tognoni, 1987)	45 (15) 17-60	52.5 (11) 28-60	U (41) = 108.5 $p < 0.05$
Stroop – Time (Caffarra et al., 2002)	36.75 (38) 10-92	23.5 (9) 12.1 70.5	U (40) = 263.5 $p = 0.08$
Stroop – Errors (Caffarra et al., 2002)	0 (1) 0-9	0 (2) 0-4	U (40) = 208.5 $p = 0.75$
Phonemic Verbal Fluency (Spreeen and Benton, 1977)	22.5 (9) 10-43	42 (25) 9-61	U (43) = 94.0 $p < 0.005$
Clock Drawing Test (0-10) (Shulman et al., 1986)	8.25 (4.25) 4-10	7 (3.5) 0-10	U (43) = 205.5 $p = 0.58$
VOSP- Screening Test (0-20) (Warrington and James, 1991)	19 (1.5) 10-20	20 (0) 18-20	U (43) = 146.0 $p < 0.05$

In addition to these neuropsychological measures, all participants underwent testing to assess for the presence of MW. This was a simple writing test, performed first by the right hand, and then the left, and composed of four different sub-tasks: signature; copying [the capital letters "B", "F" and "S"; the digits "3","4" and "9"; the upper case words "BAFFI"(mustache) and "DOLORE"(pain), the lower case cursive words "*fessura*"(crack) and "*velocità*"(speed)]; writing three words to dictation ["mela"(apple), "matita"(pencil), "manzo"(beef)]; and writing a description of a picture of a countryside scene.

Occasional MW was observed amongst both MCI patients and controls, always of individual letters (i.e. partial MW), and always when using the left (non-dominant) hand. Three MCI patients reversed letters within words: "l" in the word "velocità", "s" in the word "fessura", and "z" in the word "manzo". Control performance showed that this was not unusual, as two controls made similar errors, with one woman reversing the capital letter "S" and the numbers "3" and "9", and another similarly reversing the letter "S" and

the letters "l" and "r" in "dolore". Thus, MCI patients did not show an abnormally high prevalence of MW errors, as we had originally predicted on the basis of the classical motor hypothesis. Nonetheless, the partial MW errors observed, amongst patients and controls, were consistent with a motor basis in being specific to the non-dominant hand.

Single case study of patient FC

FC, a 59 year old woman with seven years of formal education, was originally recruited to this study as a patient with suspected MCI, based on subjective complaints of poor memory and concentration, confirmed by her husband (see later). FC is right-handed (EHI laterality quotient = +100), and declared herself not to be a re-educated left-hander.

In the screening test for MW described for the group study above, FC showed florid, complete MW when writing with her left hand (Figure 1). She reversed her signature. In the copying test, she mirror wrote all of the individual letters, two out of three numbers, and all of the upper and lower-case words (note that the m in matita appears to be mirrored vertically as well as horizontally). She similarly mirror-wrote all three words under dictation, and the entire sentence when asked to write a spontaneous description of a countryside scene: "*In un villaggio i bambini giocano*" (In a village some children are playing), though note that "bambini" is mirror-written with an intrusion ("bamibini").

Figure 1. Response sheets from the mirror writing screening test for patient FC at first assessment, writing with her left and right hand (left and right panels respectively), showing (top-to-bottom) copying, dictation and description of a picture (see text for details). For confidentiality, this figure excludes the signature writing, but this was also written normally with the right hand, and mirror-reversed with the left.

<p>Copia</p> <p>8 4 3 2 7 8 BAFFI DOLORE istituzionale</p>	<p>Copia</p> <p>fessure - velocità B.F.P. 3-49 BAFFI DOLORE</p>
<p>Scrivere le parole ascoltate</p> <p>istituzionale</p>	<p>Scrivere le parole ascoltate</p> <p>mela moltiplica momego DOLORE</p>
<p>Descriva la figura</p> <p>istituzionale</p>	<p>Descriva la figura</p> <p>In un villaggio i bambini giocano</p>

Because of her unusual performance, FC was administered a more extensive battery of neuropsychological tests than used routinely for the group study, in addition to a number of bespoke tasks aimed at investigating MW (see below). The same tests were administered to a new group of six aged-matched right-handed female controls for comparison [median age: 64 (60-67); median of years of education: 11 (5-18)]. The neuropsychological performance of FC and the six controls is summarised in Table 2. FC's performance was mostly normal except for poor scores on digit span forward and backward, and a highly unusual performance of the Rey-Osterrieth Complex Figure, which was rotated by 90 degrees (see Turnbull, Beschin, & Della Sala, 1995). In addition, at the first assessment, she showed a clear indication of a state of anxiety.

Table 2.

FC's neuropsychological performance at the three assessments. She showed Mirror Writing at the first assessment only. The median (range) performance of age-matched controls is also shown. NA (Not Available) indicates test not administered.

Test (score range)	Normal cut-off	FC assess 1 June 2012	FC assess 2 April 2013	FC assess 3 Nov 2013	Controls (N=6)
Mini Mental State Examination (0-30) (Folstein et al., 1975)	≥ 24	30	29	28	28.5 (23-30)
Frontal Assessment Battery (0-18) (Dubois et al., 2000)	≥ 13.4	18	14	NA	17.5 (14-18)
Prose Memory - Immediate recall (0-8) (Spinnler and Tognoni, 1987)	≥ 3.1	6.8	6.6	NA	5.8 (3.7-7.7)
Prose Memory - Delayed recall (0-8) (Spinnler and Tognoni, 1987)	≥ 2.39	4.4	6.6	NA	5.8 (3.4-7.7)
Digit Span forward (2-9) (Orsini et al., 1987)	≥ 3.5	3*	5	5	6 (5-6)
Digit span backward (2-9) (Orsini et al., 1987)	≥ 4.0	2*	2*	3*	4 (4-5)
Visual search (0-60) (Spinnler and Tognoni, 1987)	≥ 30	45	39.26	NA	52 (40-60)
Stroop –Time (Caffarra et al., 2002)	≤ 36.9	40*	25.5	21	21.8 (15-47)
Stroop –Errors (Caffarra et al., 2002)	≤ 4.24	4	0	0	0 (0-0)
Phonemic Word Fluency (Spreen and Benton, 1977)	≥ 17.4	28	22	NA	45 (20-59)
Rey Auditory Verbal Learning Test Immediate recall (0-75) (Rey, 1958)	≥ 28.5	67	52	53	NA
Rey Auditory Verbal Learning Test Delayed recall (0-15) (Rey, 1958)	≥ 4.7	13	14	15	NA
Clock Drawing Test (0-9.5) (Shulman et al., 1986)	≥ 5.0	7	10	NA	9.75 (8.5-10)
Rey–Osterrieth Complex Figure Immediate Copy (0-36) (Rey 1941)	≥ 23.8	2*	7.6*	27	NA
Rey–Osterrieth Complex Figure Delayed Copy (0-36) (Rey 1941)	≥ 6.3	15	28.1	9	NA
VOSP- Screening Test (0-20) (Warrington and James, 1991)	≤ 15	18	NA	NA	20 (18-20)
Activities of Daily Living (6-0) (Katz et al., 1963)		0	0	0	0
Instrumental Activities of Daily Living (8-0) (Lawton and Brody, 1969)		0	0	0	0
Geriatric Depression Scale (30-0) (Brink et al., 1982)	≤ 11	9	2	2	5.5 (3-12)
State Anxiety Inventory (80-0) (Spielberger, 1989)	≤ 53	54*	33	36	NA
Trait Anxiety Inventory (80-0) (Spielberger, 1989)	≤ 53	48	29	29	NA

Additional, bespoke tasks were as follows:

We tested writing words with transparent tiles with the right and left hand (four items each hand both in copy and dictation) (Della Sala & Cubelli, 2007). Under dictation, FC reversed two individual letters with her left hand [letter “n” in the word “cintura”(belt), and letter “n” in the word “candela”(candle), and one whole word [“rosso”(red)]. She also reversed the letter “s” in copying both “festa” (party) and “borsellino” (purse). The performance of the controls was flawless, and they were also considerably faster. For copying, FC’s total time was 186 sec and 139 sec for the right and left hand respectively, as compared with control medians 104.5 sec (range 40-121) and 115 sec (range 37-169). For dictation, FC's total time was 155 sec and 117 sec for the right and left hand respectively, as compared with control medians of 90.5 sec (range 25-150) and 113.5 sec (range 26-142).

Adapting a task reported by Critchley (1926), which can often elicit mirrored writing from normal individuals, we tested writing of words (n=8) on a sheet of paper placed against the under surface of a table, using both the left and the right hands. Under this manipulation, all words written by FC both with her right and her left hand appeared mirror reversed, but so did all six controls. FC took a total of 55 and 115 sec with her right and left hand respectively, as compared with control medians of 77.5 sec (range 37-89) and 83.5 sec (range 60-93).

Motor execution of other directional actions was assessed with the dominant hand, to see whether directional confusion applied to directional actions other than writing. We tested the execution of five asymmetric actions to command, with props provided (screw on a jar lid, screw on a bottle cap, open a lock, screw in a screw with a screwdriver, screw in a

light bulb).FC took a total of 28 seconds to carry out the five motor actions, compared with a control median of 24.5 seconds (range 22-33), and she did so flawlessly, with no sign of directional confusion.

Perception of mirrored-forms was assessed by reading of words and sentences in cursive or block letters written backwards on paper (four words, four short sentences) and written forward but viewed in a mirror (four words, four short sentences). FC did not show any facility for reading backward text. Indeed, she found this task difficult, taking a total of 334 sec. to read the four words and four sentences written backwards on paper, committing six errors, compared to a control median of 53 sec (range 19-97), with median zero errors (range 0-5). Similarly, FC took a total of 180 sec. to read the four words and four sentences in a mirror, committing three errors, compared to a control median of 53.5 sec (range 11-108), with median 2 errors (range 0-6).

Finally, and somewhat speculatively, we asked FC to discriminate the laterality (left or right) of 48 individually-viewed pictures of hands rotated at various angle. This task, adapted from Parsons (1987), has been widely used as a test of motor imagery, and there has been some suggestion of abnormal motor imagery in MW (McIntosh & Della Sala, 2012). However, FC performed quite normally, scoring 42/48 correct, and performing the whole task in 152 sec, compared to a control median of 43/48 correct (range 0-17) in 223 sec (80-448).

Longitudinal assessment and clinical interviews

FC was followed up at 10 and 15 months after the initial assessment described above (see Table 2). Her MW was no longer apparent in these two subsequent testing sessions. She

reversed only one letter ("S") and one number ("9") in the MW screening test when writing with her left hand in the first follow-up session, and none in the second, and her performance did not differ from that of controls in any of the MW-related tests. She performed normally in all cognitive tests except digit span backwards. Indeed, her overall performance had improved over time; hence the initial diagnosis of MCI proposed during the original clinical examination in the neurology out-patient surgery was rejected.

At all three testing sessions, FC received, in addition to cognitive assessments, formal clinical interviews and questionnaires to assess her mood given by a trained Clinical Psychologist (see Table 2). From the clinical interviews it appeared that she had an anxiety disorder. At the time of the first assessment, during which MW was identified, the patient was experiencing significant levels of stress due to a number of adverse family events, and she scored in the pathological range for State Anxiety (Spielberger, 1989; see Table 2). She described that period as characterized by excessive burden and apprehension, with negative emotions difficult to control. F.C. reported that she felt confused, with considerable memory and concentration difficulties, which was confirmed by her husband. Moreover, the patient felt irritable and restless in carrying out activities of daily living. During the interviews it became apparent that the focus of the anxiety and worry was not confined to features of an Axis I disorder, (e.g., Panic Disorder or Obsessive-Compulsive Disorder) and was not due to the side effects of drugs or general medical conditions. Taking into account all these symptoms, it appeared that the patient was suffering from Generalized Anxiety Disorder (GAD) consistently with the criteria of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV TR, 2000).

During the third and final assessment both the patient and her husband claimed that her memory difficulties and episodes of confusion and distress had disappeared. In November 2013, the patient acknowledged that her mood had returned to normal (as had her State Anxiety score, see Table 2) and that her agitation in carrying out everyday activities had faded away.

Discussion

The main thrust of the current group study is that Mirror Writing (MW) is not a typical feature of MCI. However, one patient (FC) mis-labelled initially as MCI, in fact in a state of anxiety, presented with full-blown MW, which was not present at follow-up once her anxiety had resolved.

The lack of MW in MCI, over and above what is expected in a group of elderly people (see Balfour et al., 2007), does not support our original prediction based on the classical motor hypotheses. This hypothesis (Critchley, 1928) advocates that the critical motor representation specifies sequences of muscle commands for writing with the dominant hand. If a person tries to execute such a sequence with the non-dominant hand, the action will be mirror-reversed, due to anatomical mirroring between the arms, unless a cognitive effort is made to transform the motor sequence. The cognitive impairment shown by the MCI patients then could have resulted in at least some of them being prone to MW when writing with the left hand. This was not the case. On the other hand, this null result does not refute the classical motor hypothesis either, since it is plausible that cognitive deterioration was not severe enough in any MCI patient to cross a threshold for MW to emerge. However, the single case report of patient FC does seem to show that reduced

control over one's own cognition, albeit borne of anxiety rather than neurodegeneration, can indeed cause complete MW as a transitory symptom.

The case of FC supports the notion that MW can be triggered by high levels of angst, as signalled in the reports of early series of mirror writers and insinuated by anecdotal observations. In his dissertation, Fuller (1916; see also Fuller, 1908) compiled a series of detailed observations on MW associated with a variety of causes leading to partial alteration of consciousness, and noted the phenomenon in an “hysteric” person (p. 216), an observation reiterated by Critchley (1928, p. 28). Charcot's famous “hysterical” patient Blanche was also reported to mirror write (Hustvedt, 2012, p.123). Both Fuller (1916) and Mills (1894) described the case of telegraphists who “working their transmitting key with the right hand scribble down the incoming messages mirror-wise with the left hand” (Critchley, 1928, p.15). Bisch (1925) lists MW as one of the “neurotic manifestations in adolescence”. Bennet (1960) reports on the case of a six year old left-handed child named Colin, affected by “primary behaviour disturbances with pronounced neurotic trends”, who presented with MW.

More recent pointers to the possible appearance of MW in people under severe stress can be culled from scant case reports. Le, Smith and Cohen (2009) describe the case of Ms. A, a 46-year old woman whose family had “recently experienced enormous stress” and who presented with an episode of dissociative identity disorder characterised by MW. A similar case was reported by Nakano, Endo and Tanaka (2003). Finally, there is the anecdotal observation of a highly educated left-handed 49-year old man, who, during a considerably stressful period of his life, experienced compulsory MW when writing with his left hand, which regressed following benzodiazepine treatment (Della Sala, 2006).

The case of FC, whom we have followed up for 18 months, is the most compelling and complete report yet of MW due to anxiety.

As a caveat, although the clinical appraisal was that FC was suffering from GAD (DSM-IV TR, 2000), which resolved along with her MW, her scores on formal anxiety questionnaires (Spielberger, 1989) were only marginally into the pathological range. Nonetheless, anxiety remains the most compelling explanation for her behaviour. It is far less likely, for instance, that FC's behaviour was due to a failure to understand task instructions, notwithstanding her relative lack of education (7 years). Indeed, none of the matched control group made equivalent errors; and FC was debriefed at the end of each session, to check that she had understood her task. Importantly, her mirror writing vanished along with the reduction in her anxiety.

Turning to the proximal functional basis of this behaviour, FC's MW cannot be interpreted as resulting from a perceptual impairment; her performance is more easily accounted for by implying a deficit in the motor transformation of writing actions to be executed with the non-dominant hand. She is fully right handed. She did not show mirror reading. She was also as accurate as the controls in executing directional actions, and in tasks of left-right discrimination, hence ruling out general problems with selecting movement directions. FC's performance confirms that MW is typically confined to the non-dominant hand and is not normally accompanied by mirror-reading (Critchley, 1927, 1928; Della Sala & Cubelli, 2007; McIntosh, de Lucia & Della Sala, 2014; but see for possible exceptions Heilman et al, 1980, and Durwen & Linke, 1988). Taken together these observations favour a motor over a perceptual account of FC's MW.

Clinical data are supportive of the motor account of MW, according to which two circumstances conspire to induce the symptom. The first is that the person must attempt to write with the non-dominant hand. This often applies to right-handed people after left hemisphere stroke, since dominant upper limb movement is frequently compromised. The second circumstance is simply any cognitive factor (e.g., reduced alertness) that hampers the ability of transforming the normal writing pattern to adapt it for left hand use, and/or of monitoring performance for errors; this factor was severe anxiety in the case of FC. Accordingly, the symptom can be associated with a range of aetiologies, including head injury (Striefler & Hoffman, 1976), Parkinson's disease, and essential tremor (Tashiro et al, 1987). Tellingly, when right hemisphere damaged patients are asked to write with the left hand, which they are unlikely to do spontaneously, mirrored letters arise as commonly as they do amongst left-hemisphere damaged patients (Balfour et al, 2007). But brain damage may not even be necessary, since mirror writing errors have been associated with forced left hand use after amputation (Schott, 1980), and even noted in normal adults asked to write with the non-dominant hand (Balfour et al., 2007).

Some more tangential aspects of FC's case also deserve comment. At her first assessment, when MW was florid, she also showed occasional reversals when asked to write with transparent tiles, even once reversing a whole word ("rosso"). This behaviour echoes that of a patient studied by Della Sala and Cubelli (2007), with a left fronto-parietal lesion, who spelt words out from right-to-left when arranging magnetic tiles with the left hand [e.g. 'SEGA' (saw) became 'AGEZ'; note the 'Z' for the 'S']. In the current case of *transparent* tiles, however, it is possible to invert each tile, so that the letter forms are also reversed, and FC did so several times. It is unlikely that these were perceptual errors, because FC showed no abnormalities in other perceptual tasks. But the behaviour

is not easily accommodated by the classical motor hypothesis either, since writing with tiles, as opposed to handwriting, is not a well-learned action for most people (aficionados of the board game "Scrabble" may be exceptions), and the action of placing a transparent tile does not stipulate which way up the tile should be placed, and thus whether the letter faces forward or backward.

There are thereby two aspects of this tile-placing behaviour that need to be explained: the ordering of tiles from right-to-left, and the reversal of individual tiles. The right-to-left ordering of tiles is important because it suggests that MW is not tightly specific to graphic actions. As Della Sala and Cubelli argue (2007), this counters any account of MW as manifestation of a peripheral dysgraphia simply due to deficits in executing a motor programme (Ellis, 1988). Nonetheless, one might posit that the task has a close enough conceptual relation to writing that the overlearned tendency to progress abductively outward from the body midline is preserved, and FC fails to modify this direction when working with the left hand. This would then create a tension with the placement of the individual tiles. That is, for a letter to face 'towards' the next in the sequence, FC would need to invert the tile, reversing the letter form, but her preserved perceptual abilities would tend to alert her to such errors and help her to correct her actions. This antagonism might explain why errors in this tile task were relatively rare, in contrast with consistent MW for the more automatic action of handwriting.

Another task included, for exploratory purposes, was Critchley's(1926) under-the-table writing, which quite reliably elicits mirrored writing from normal people. No empirical report has systematically evaluated this task. However, as the under-the-table arrangement has the usual effect of reversing a person's writing, one plausible prediction

would have been that FC should produce MW with the right hand under the table, but write forward script with her left. Instead, FC and all six controls produced MW under the table with left and right hands alike. This is in fact consistent with Critchley's original comments: "Another means whereby mirror writing may be obtained from a normal individual is to get him to write with his right or left hand on the under surface of a card or on a piece of paper held up against the brow" (Critchley, 1926, p. 27). This pattern suggests that people may commonly perform this unusual task by imaginatively projecting the under-the-table writing onto its upper surface, as if viewing the writing through a glass tabletop. If so, writing in this format may be guided by visual imagery, rather than just by motor habit, which would imply that the causes of MW in this idiosyncratic situation are rather distinct from the usual causes of MW in more conventional writing situations. FC's pattern of performance in this task, which matches that of the controls, would then indicate that her ability to visually imagine words in their correct orientation was preserved, providing a further argument in favour of a motor, rather than a perceptual, interpretation of her MW.

Overall, our group study of MCI patients finds no evidence for elevated levels of MW in this clinical population; but our single-case observations of patient FC powerfully confirm prior anecdotal reports that MW can arise as a florid, transient symptom of anxiety. The character of FC's anxiety-induced MW is compatible with a motor, rather than a perceptual account.

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